Ocean Monitoring, Coastal Studies and Remote Sensing

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LONG-TERM GOALS

The long-term goal of this research is to develop and test predictive models for nearshore and coastal processes. Initial development and testing of models is to be accomplished through monitoring over a broad range of spatial and temporal scales. Model development is to be accomplished within the framework of the nearshore as a hierarchical complex system, wherein, at discretely ordered space and time scales, a small number of variables emerge as the dominant influences on the dynamics of this nonlinear, open system and the interactions between these dominant variables give rise to complex, emergent behavior.

OBJECTIVES

The specific objectives of this research project are (i) to identify the dominant variables and processes operative in the nearshore and in its connection to processes on the continental shelf; (ii) to formulate and develop predictive, hierarchical complex systems models for nearshore processes and features, including sand bars, megaripples, breaking waves, infragravity wave generation, surf zone currents, and swash zone flow and morphology; (iii) to monitor (on time scales ranging from seconds to years and spatial scales ranging from meters to kilometers) nearshore and offshore bathymetry and hydrodynamics and to determine the coupling between them; (iv) to relate complex systems models to measurements acquired through remote sensing; (v) to propose and design new field experiments capable of refuting complex systems and competing models.

APPROACH

Computer simulations, theory and field observation, experimentation and monitoring are combined to formulate, develop, test and refine models for nearshore hydrodynamics and bathymetry and their coupling to processes on the continental shelf.

Nearshore processes are nonlinear and dissipative. For systems with these characteristics, the traditional Reductionist Approach (fundamental physics/equations) fails because of a lack of defensible criteria for selecting dominant dynamical variables; and Universalist approaches (simple mechanisms that apply

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across categories of systems or universality classes) fail because the simplifying assumptions underlying Universalist models necessarily imply an inability to treat the variability and complexity inherent in the natural environment (external to the system being studied).

In contrast, the modeling and model-testing methodology adopted for this research is in concert with the nonlinear, open nature of nearshore processes. This hierarchical modeling approach for nearshore systems partially overlaps with methodologies adopted in physics (e.g., Synergetics: Haken, 1983) and ecology (Hierarchy Theory: Ahl and Allen, 1996), but differs from the former in avoiding the need to use systems of equations as a starting point and from the latter in its emphasis on objective variable selection via observation and description. It can be summarized with the following four steps:
(i) delineate the boundaries of the open system;
(ii) identify and temporally order dynamical variables of the systems and variables in the external environment affecting the system dynamics;
(iii) for selected levels in this temporal hierarchy, encapsulate the dynamics of faster variables into a minimal set of rules that relate variables at this level to each other and to the external environment;
(iv) formulate models at these selected levels and derive testable predictions of the models.

Variable selection in the nearshore depends largely on spatial and temporal localization of features and dynamics (e.g., the crests of bedforms or sand bars), but cannot be predicted from first principles; rather, observations acquired through monitoring on a broad range of spatial and temporal scales are a necessary step in determining the position of and relationships between variables in the hierarchy. In a practical sense, a broad range of scales can only be achieved through monitoring the nearshore with remote sensing. Sensitive tests of models rely on the prediction and measurement of transient behavior, which is a fundamental aspect of natural (in contrast to laboratory) systems.

WORK COMPLETED

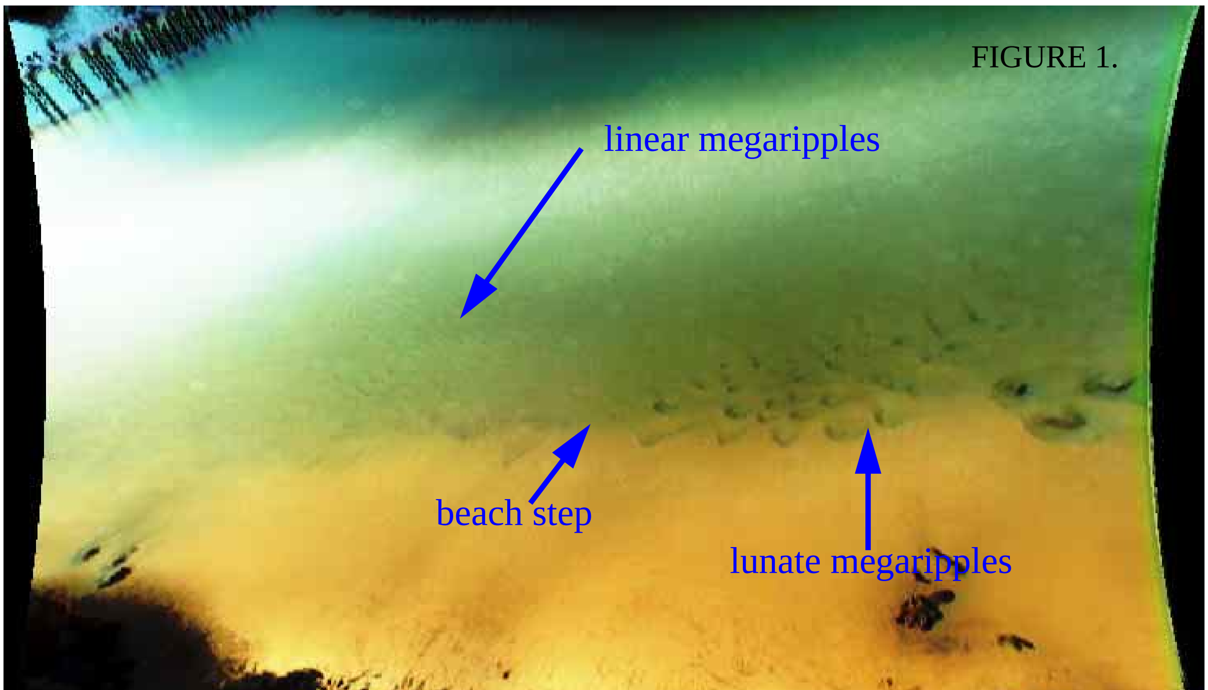
(i) a new remote sensing video technique was developed to measure the inception, evolution and destruction of megaripples and other nearshore bathymetric features; (ii) this technique has been ground-truthed and continuous monitoring of the surf zone has been implemented at Scripps Beach; (iii) models for mean spacing and orientation of bedforms based on the dynamics of bedform crest terminations have been developed and applied to nearshore ripples and megaripples; (iv) a model for rip currents based on a dissipative interaction between waves and localized offshore currents was developed and subjected to preliminary testing.

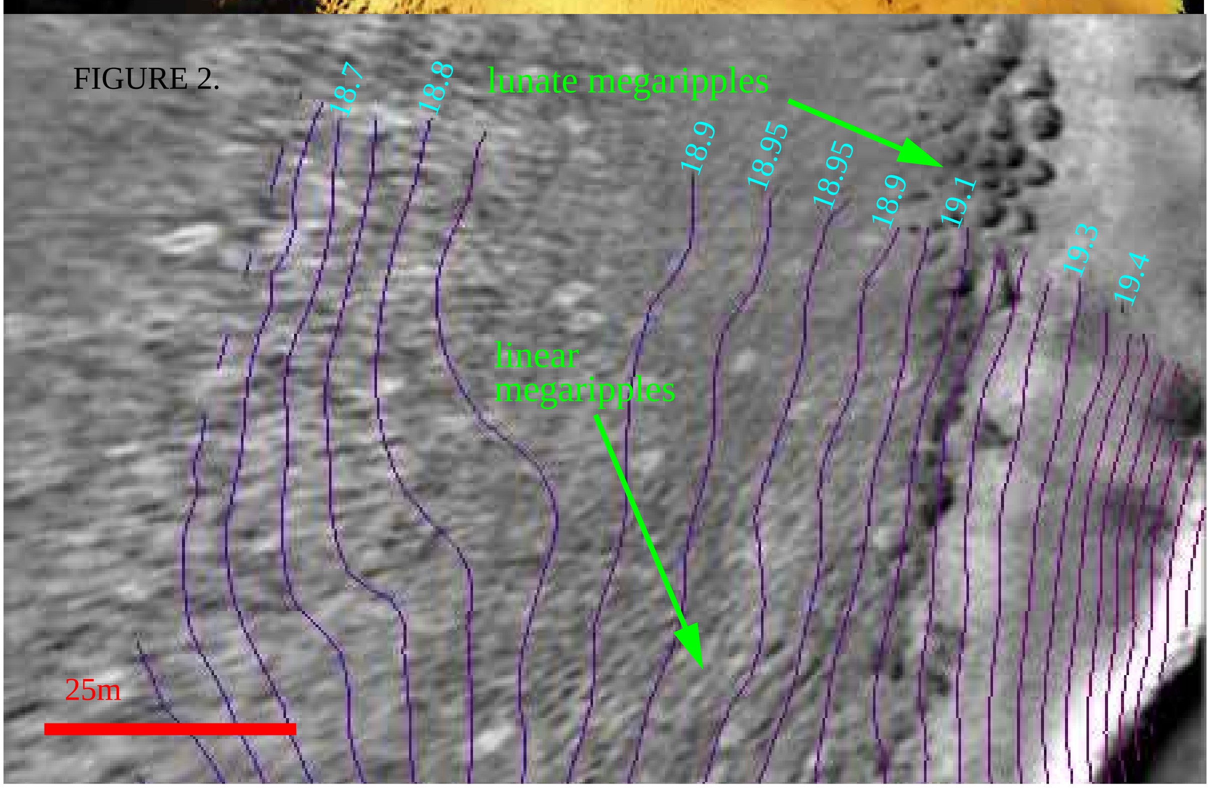
RESULTS

In an effort led by graduate student Linden Clarke, a new technique for imaging nearshore morphology with video has been developed. Video frames acquired from a camera viewing the surf and swash zones from a cliff are downloaded to a workstation, processed to remove pixels from breaking waves or foam, averaged over a period of several minutes and false-color-enhanced to emphasize bathymetric features. Depending on conditions and field of view, crests of bedforms including megaripples, sand bars, rip channels, and sediment and cobble transport patterns can be extracted. Resolution is degraded by large waves, sediment-laden or bio-fouled water and glare. This technique currently is being used to acquire continuous images of nearshore bathymetric patterns (at 5-10 minute intervals) during daylight hours on Scripps Beach.

This technique is one component of an effort to monitor the connection between sediment and

bathymetry outside the surf zone and bathymetry and bathymetric patterns within the surf zone. An example of an obliquely-viewed image (averaged over 10 minutes) from Scripps Beach is given in Figure 1, showing lunate megaripples forming near a prominent beach step, with a set of obliquely-oriented linear megaripples offshore and to the south (left). This image is converted into map view and filtered to equalize brightness across the image, in an attempt to better detect bedforms throughout the surf zone (Figure 2). Measured bathymetric contours from a wading survey using a water-resistant GPS unit are superimposed.





In an effort led by postgraduate researcher Jeff Babcock, the purchase of an acoustic, swept-source (CHIRP) seafloor imaging system is planned so that observations of seafloor bathymetry can be extended offshore of the surf zone, processes associated with the exchange of sediment between offshore and the nearshore can be investigated, and seafloor tectonic structure along continental margins can be measured. The advantage of the CHIRP system derives from its bottom penetrating capability (used to image sub-seafloor structure) in combination with high-resolution side-scan sonar, which produces detailed images of the seafloor. The shallow water, high-resolution Datasonics SIS-1000 Seafloor Imaging System (or equivalent) will be obtained through a combination of NSF Shipboard Equipment funds, SIO matching funds and a contribution from the ONR Chair award.

The CHIRP instrument can be used to image seafloor depth and subsurface features in water depths ranging from a few meters up to nearly a kilometer. The CHIRP system is suitable for work on all Scripps research vessels and can be towed by smaller boats in shallow water (<2 m).

In the fall of 1997 the Datasonics SIS-1000 system was deployed from the R/V Melville off the coast of San Onofre to determine its capabilities for this research. A 4x4km sidescan image is shown in Figure 3. Dark features in the image correspond to outcrops of basement rock. Figure 4 gives a closer view of striations observed on the sandy bottom in water ~20m deep. Enhanced data acquisition software provided real-time mosaics of side-scan data, permitting immediate assessment of data quality and coverage. This system complements bathymetry and bathymetric patterns currently being acquired in the surf zone by extending measurements to greater water depths. The instrument will permit the tracking of sand from the surf zone offshore during storms and back into the surf zone during the summer. Permanent offshore sinks of sand will be quantified.

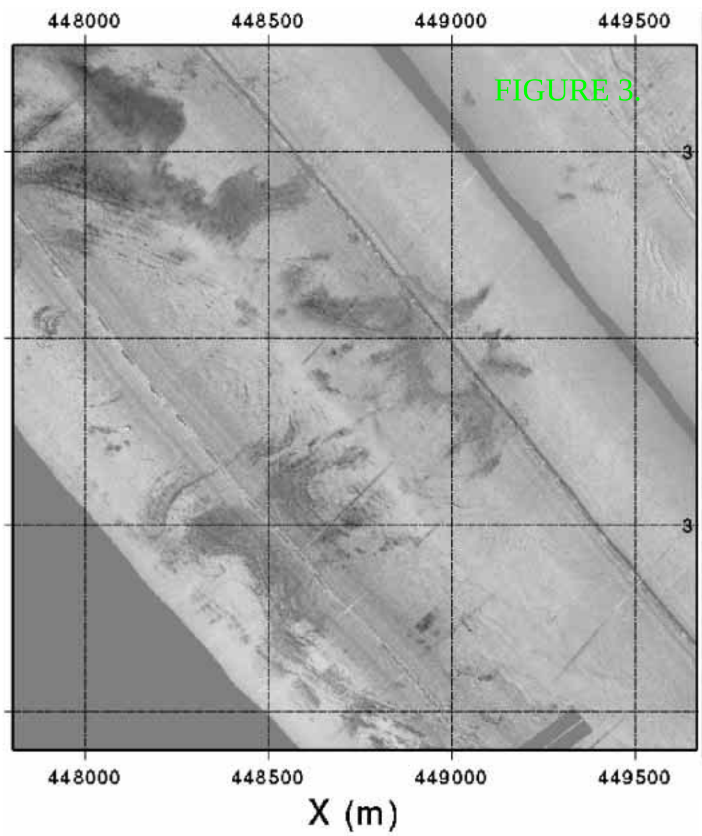


FIGURE 3.

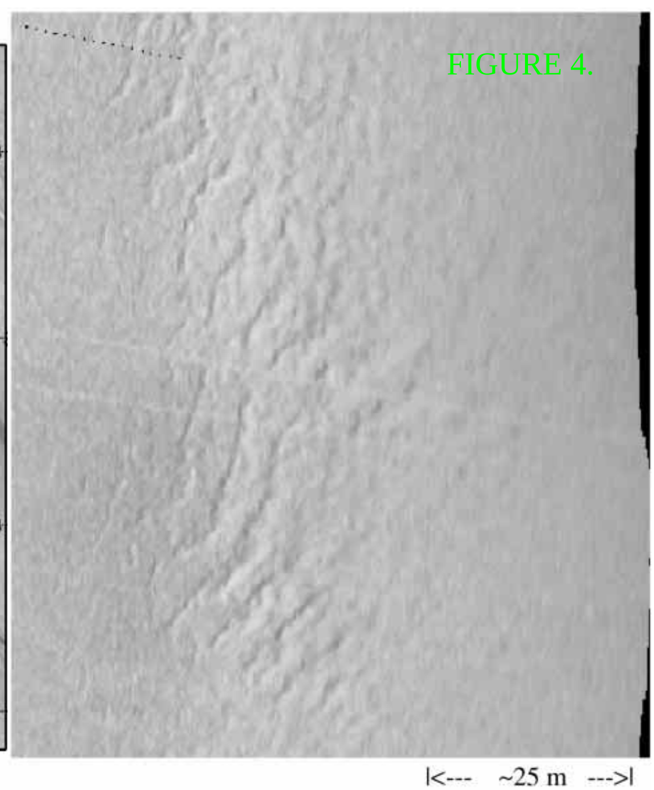


FIGURE 4.

Models for the mean orientation, mean spacing and mean density of defects (bedform crest line terminations) were developed based on the following two hypotheses: (i) bedforms change orientation when defects pointing in opposite directions along the crest lines migrate at different speeds; (ii) bedforms change spacing as defects migrate through a field of bedforms: each time a defect passes through a continuous crest line, a short length of crest line is lost, resulting in an overall increase in spacing. Bedform orientation is predicted as a function of a sequence of transport events for which sediment transport direction, magnitude and duration are specified. The model for bedform orientation results in predictions consistent with an empirical model (Rubin and Hunter, 1987) if the duration of transport events (the period over which transport is averaged) is longer than the time required for defects to migrate the distance between bedforms. Therefore, the orientation of large bedforms in the surf zone, such as megaripples, is not expected to be sensitive to transport over a wave period (although it could be sensitive to wave-driven mean transport), and the direction of bedform orientation is expected to provide a reliable proxy for sediment transport direction under a broad range of conditions where bedform displacements are significant on tidal time scales and defect density is high. Bedform spacing is predicted to increase logarithmically with time, but at a much slower rate under reversing flows than in steady flow conditions. The model is consistent with observations of an approximately linear increase of spacing with wave orbital diameter D when D is low, with a slower rate of increase at higher D. In addition, bedform spacing is sensitive to the size of the bedform field, suggesting that laboratory experiments with small test sections might not reflect natural bedform spacing and dynamics.

In a model of rip currents developed by postgraduate researcher Brad Murray (now a member of the faculty at Duke University), the complicated processes of water transport by waves and currents and sediment transport are encapsulated into minimal rules that express the effect of these processes at the length and time scales of rip currents. A key feature of the model is an interaction in which a rip current decreases the wave height locally, as commonly has been noted from visual observations. This interaction renders an alongshore-uniform set up unstable, leading to narrow, pulsating rip currents. Modeled rip current spacing, width, velocity and duration have been found to depend on basic characteristics of waves, especially wave height and alongshore continuity of crests, and beach slope (width of surf zone). Model predictions of spatial and temporal variation in offshore current velocity are qualitatively consistent with measurements made on Scripps Beach (Smith and Largier, 1995). In semi-quantitative tests of the model, the frequency, duration, spacing and width of rip currents were measured from videotape acquired by a camera overlooking Torrey Pines Beach. Preliminary comparisons indicate that the model can reproduce the measurements using realistic model parameters.

IMPACT / APPLICATIONS

The development, implementation and testing of hierarchical complex systems models for nearshore processes permit an assessment of the hierarchical modeling methodology versus Reductionist and Universalist approaches for modeling the nearshore and its connection to processes offshore and for modeling other complicated natural systems.

RELATED PROJECTS

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